



## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (51) International Patent Classification 7 :<br>C07C 1/04, C10G 2/00, C07C 11/04,<br>29/151                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | A1 | (11) International Publication Number: <b>WO 00/15587</b><br>(43) International Publication Date: 23 March 2000 (23.03.00)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| (21) International Application Number: PCT/GB99/02955                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |    | (81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CR, CU, CZ, DE, DK, DM, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). |
| (22) International Filing Date: 7 September 1999 (07.09.99)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| (30) Priority Data:<br>9819645.4 10 September 1998 (10.09.98) GB                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| (71) Applicant (for all designated States except US): BP CHEMICALS LIMITED [GB/GB]; Britannic House, 1 Finsbury Circus, London EC2M 7BA (GB).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| (72) Inventors; and<br>(75) Inventors/Applicants (for US only): GRIFFITHS, David, Charles [GB/GB]; 75 Common Road, Claygate, Esher, Surrey KT10 0HU (GB). MAUNDERS, Barry, Martin [GB/GB]; Woodlands, 5 Paddock Way, Woodham, Woking, Surrey GU21 5TB (GB). WOODFILM, William, Terence [GB/GB]; 25 Four Acre Coppice, Hook, Hampshire RG27 9NF (GB).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| (74) Agent: SMITH, Julian, Phillip, Howard; BP International Limited, Group Patents & Agreements, Chertsey Road, Sunbury-on-Thames, Middlesex TW16 7LN (GB).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| (54) Title: PROCESS FOR THE PREPARATION OF MONO-OLEFINS FROM PARAFFINIC HYDROCARBONS                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <pre> graph LR     1[HYDROCARBON] --&gt; 11[11]     10[NATURAL GAS] --&gt; 11     11 --&gt; 13[13]     13 --&gt; 15[15]     15 --&gt; 17[17]     17 --&gt; 18[DIESEL]     15 --&gt; 6[6]     6 --&gt; 7[ETHYLENE, HIGHER OLEFINS]     2[O2] --&gt; 6     1 --&gt; 6     </pre>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| (57) Abstract                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| <p>A process for the production of a mono-olefin from a feedstock comprising a paraffinic hydrocarbon which process comprises the steps of: (a) feeding the feedstock and a molecular oxygen-containing gas to an autothermal cracker wherein they are reacted by oxidative dehydrogenation to form a product comprising one, or more, mono-olefin(s) and synthesis gas, (b) separating the product from step (a) into a synthesis gas-containing stream and one, or more, olefins and recovering the one, or more, olefin(s), (c) contacting synthesis gas-containing stream separated in step (b) with either: (i) a catalyst for the conversion of synthesis gas to methanol under conditions whereby synthesis gas is converted to methanol; or (ii) a catalyst for the water gas shift reaction under conditions whereby carbon monoxide in the synthesis gas is converted by reaction with water to hydrogen and carbon dioxide and thereafter recovering hydrogen; or (iii) a catalyst for the conversion of synthesis gas to hydrocarbons under conditions whereby synthesis gas is converted to a hydrocarbon product, and thereafter recovering at least a part of the hydrocarbon product.</p> |    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

|    |                          |    |                                          |    |                                              |    |                          |
|----|--------------------------|----|------------------------------------------|----|----------------------------------------------|----|--------------------------|
| AL | Albania                  | ES | Spain                                    | LS | Lesotho                                      | SI | Slovenia                 |
| AM | Armenia                  | FI | Finland                                  | LT | Lithuania                                    | SK | Slovakia                 |
| AT | Austria                  | FR | France                                   | LU | Luxembourg                                   | SN | Senegal                  |
| AU | Australia                | GA | Gabon                                    | LV | Latvia                                       | SZ | Switzerland              |
| AZ | Azerbaijan               | GB | United Kingdom                           | MC | Monaco                                       | TD | Chad                     |
| BA | Bosnia and Herzegovina   | GE | Georgia                                  | MD | Republic of Moldova                          | TG | Togo                     |
| BB | Barbados                 | GH | Ghana                                    | MG | Madagascar                                   | TJ | Tajikistan               |
| BE | Belgium                  | GN | Guinea                                   | MK | The former Yugoslav<br>Republic of Macedonia | TM | Turkmenistan             |
| BF | Burkina Faso             | GR | Greece                                   |    |                                              | TR | Turkey                   |
| BG | Bulgaria                 | IU | Hungary                                  | ML | Mali                                         | TT | Trinidad and Tobago      |
| BJ | Benin                    | IE | Ireland                                  | MN | Mongolia                                     | UA | Ukraine                  |
| BR | Brazil                   | IL | Israel                                   | MR | Maritania                                    | UG | Uganda                   |
| BY | Belarus                  | IS | Iceland                                  | MW | Malawi                                       | US | United States of America |
| CA | Canada                   | IT | Italy                                    | MX | Mexico                                       | UZ | Uzbekistan               |
| CF | Central African Republic | JP | Japan                                    | NE | Niger                                        | VN | Viet Nam                 |
| CG | Congo                    | KE | Kenya                                    | NL | Netherlands                                  | YU | Yugoslavia               |
| CH | Switzerland              | KG | Kyrgyzstan                               | NO | Norway                                       | ZW | Zimbabwe                 |
| CI | Côte d'Ivoire            | KP | Democratic People's<br>Republic of Korea | NZ | New Zealand                                  |    |                          |
| CM | Cameroon                 | KR | Republic of Korea                        | PL | Poland                                       |    |                          |
| CN | China                    | KZ | Kazakhstan                               | PT | Portugal                                     |    |                          |
| CU | Cuba                     | LC | Saint Lucia                              | RO | Romania                                      |    |                          |
| CZ | Czech Republic           | LI | Liechtenstein                            | RU | Russian Federation                           |    |                          |
| DE | Germany                  | LK | Sri Lanka                                | SD | Sudan                                        |    |                          |
| DK | Denmark                  | LR | Liberia                                  | SK | Sweden                                       |    |                          |
| EE | Estonia                  |    |                                          | SG | Singapore                                    |    |                          |

**PROCESS FOR THE PREPARATION OF MONO-OLEFINS FROM  
PARAFFINIC HYDROCARBONS**

The present invention relates in general to the production of mono-olefins by the oxidative dehydrogenation of gaseous paraffinic hydrocarbons having two or more carbon atoms and in particular to the production of mono-olefins by autothermal cracking, especially of ethane, propane, and butanes.

5        A known commercial route to the production of olefins is via steam cracking of paraffinic hydrocarbons. Steam cracking involves pyrolysis of the hydrocarbons. Olefins can also be prepared by cracking a paraffinic feed wherein the heat required for pyrolysis is provided by the partial combustion of the feedstock and not by conventional tubular fired heaters as in steam cracking. This process can be described as "autothermal

10      cracking" and will be described as such hereinafter. Autothermal cracking may be accomplished in the absence of a catalyst, as described in for example, an article entitled "Autothermal Cracking for Ethylene Production" by R. M. Deanesly in Petrol. Refiner, 29 (September, 1950), 217 and GB-A-794,157, or in the presence of a catalyst capable of supporting combustion beyond the normal fuel rich limit of flammability as described

15      in, for example, EP-A-0164864; EP-A-0178853; EP-B1-0332289; EP-B1-0529793; and EP-A-0709446.

EP-A-0164864 and EP-A-0178853 describe the production of olefins together with carbon monoxide and hydrogen from gaseous paraffinic hydrocarbons, including ethane, by partial oxidation in spouted or fluid bed reactors. EP-A-0178853, for

20      example, discloses a process for the preparation of synthesis gas (carbon monoxide and hydrogen) from a hydrocarbon feed wherein the saturated hydrocarbon and an oxygen-containing gas are introduced in a ratio of 1.1 to 5 times the stoichiometric ratio of

hydrocarbon to oxygen for complete combustion. This process does not require a catalyst for its operation.

EP-B1-0332289 provides a process for the production of a mono-olefin from a gaseous paraffinic hydrocarbon having at least two carbon atoms or a mixture thereof by

5 partially combusting a mixture of the hydrocarbon(s) and a molecular oxygen-containing gas in a composition of from 5 to 9 times the stoichiometric ratio of hydrocarbon to molecular oxygen-containing gas for complete combustion to carbon dioxide and water, in contact with a catalyst capable of supporting combustion beyond the normal fuel rich limit of flammability.

10 EP-B1-0529793 discloses a process for the production of mono-olefins from a paraffin-containing hydrocarbon feed having at least two carbon atoms, the process comprising

(A) a first step of partially combusting a mixture of the hydrocarbon feed and a molecular oxygen-containing gas in contact with a catalyst capable of supporting

15 combustion beyond the normal fuel rich limits of flammability, said first step carried out under a total pressure of greater than 5 bar absolute and at a temperature of greater than 650°C, and

(B) a second step of cooling the mono-olefinic products to 600°C or less within less than 50 milliseconds of formation.

20 Finally, EP-A-0709446 discloses a process for the conversion of a liquid paraffin-containing hydrocarbon which comprises the steps of:

(a) partially combusting a mixture of the liquid hydrocarbon and a molecular oxygen-containing gas in a reaction chamber with a catalyst capable of supporting combustion beyond the normal fuel rich limit of flammability, the mixture having a stoichiometric ratio of hydrocarbon to oxygen of greater than the stoichiometric ratio required for complete combustion to carbon dioxide and water, to produce a product stream and a carbon deposit in the reaction chamber;

25 (b) periodically replacing the liquid hydrocarbon and molecular oxygen-containing gas mixture in step (a) with a fuel-rich carbon-containing stream for a period of time sufficient to effect substantial removal of the carbon deposit from the reaction chamber.

In addition to the valuable olefinic product(s) the autothermal cracking reaction

produces both carbon monoxide and hydrogen, which in admixture is hereinafter to be referred to as "synthesis gas". The resulting synthesis gas from autothermal cracking is usually used as a fuel. This is a problem because it represents a waste of a valuable resource and therefore imposes an economic penalty on the process. A solution to this

5 problem is to recover the synthesis gas and convert it to higher value products.

Accordingly, the present invention provides a process for the production of a mono-olefin from a feedstock comprising a paraffinic hydrocarbon which process comprises the steps of:

- (a) feeding the feedstock and a molecular oxygen-containing gas to an  
10 autothermal cracker, where they are reacted by oxidative dehydrogenation to form a product comprising one or more mono-olefin(s) and synthesis gas,
- (b) separating the product from step (a) into a synthesis gas-containing stream and one or more olefins and recovering the one or more olefin(s),
- (c) contacting synthesis gas-containing stream separated in step (b) with either:-  
15 (i) a catalyst for the conversion of synthesis gas to methanol under conditions whereby synthesis gas is converted to methanol, and optionally thereafter or simultaneously contacting the methanol so-formed with a catalyst for the dehydration of methanol to ethylene, under conditions whereby methanol is converted to ethylene and recovering the ethylene, or optionally methanol or both; or
- 20 (ii) a catalyst for the water gas shift reaction under conditions whereby carbon monoxide in the synthesis gas is converted by reaction with water to hydrogen and carbon dioxide and thereafter recovering hydrogen; or
- (iii) a catalyst for the conversion of synthesis gas to hydrocarbons under conditions whereby synthesis gas is converted to a hydrocarbon product and thereafter  
25 recovering at least a part of the hydrocarbon product.

The term "oxidative dehydrogenation" is not intended to be limiting in any way and broadly describes the chemistry involved. It is believed that both partial oxidation and cracking occur in the reaction.

The feedstock may be oxidatively dehydrogenated in the autothermal cracker in  
30 the presence or absence of a catalyst capable of supporting combustion beyond the normal fuel rich limit of flammability, preferably in the presence of such a catalyst. The principal role of the catalyst is to stabilise partial combustion of the gaseous mixture

which may not otherwise be flammable. Suitably the catalyst is a supported platinum group metal. Preferably, the metal is either platinum or palladium, or a mixture thereof. Although a wide range of support materials are available, it is preferred to use alumina as the support. The support material may be in the form of spheres, other granular shapes 5 or ceramic foams. Preferably, the foam is a monolith which is a continuous multichannel ceramic structure, frequently of a honeycomb appearance. A preferred support for the catalytically active metals is a gamma alumina. The support is loaded with a mixture of platinum and palladium by conventional methods well known to those skilled in the art. The resulting compound is then heat treated to 1200°C before use. Catalyst promoters 10 may also be loaded onto the support. Suitable promoters include copper and tin.

The catalyst may be used as a fixed bed or as a solids recirculating bed, for example a fluid or spouted bed. Use of the catalyst in a fixed bed can avoid the problem of attrition, which is mainly associated with moving bed operations. Moreover, the use of a fixed bed also facilitates rapid quenching of the products as compared with the use 15 of a fluid bed.

In the process for the production of a mono-olefin from a feedstock comprising a gaseous paraffinic hydrocarbon the paraffinic hydrocarbon may suitably be ethane, propane or butane. The paraffinic hydrocarbon may be substantially pure or may be in admixture with other hydrocarbons and optionally other materials, for example methane, 20 nitrogen, carbon monoxide, carbon dioxide, steam or hydrogen. A paraffinic hydrocarbon-containing fraction such as naphtha, gas oil, vacuum gas oil, or mixtures thereof, may be employed. A suitable feedstock is a mixture of gaseous paraffinic hydrocarbons, principally comprising ethane, resulting from the separation of methane from natural gas. A preferred feedstock is a paraffinic hydrocarbon principally 25 comprising ethane which provides a product principally comprising ethylene as the mono-olefin.

As the molecular oxygen-containing gas there may suitably be used either oxygen or air. It is preferred to use oxygen, optionally diluted with an inert gas, for example nitrogen. It is preferred to pre-mix the oxygen-containing gas and the paraffinic 30 hydrocarbons feedstock prior to contact with the catalyst, when present. In the presence of a catalyst the composition of the gaseous paraffinic hydrocarbon/molecular oxygen-containing gas mixture is suitably from 5 to 13.5 times the stoichiometric ratio of

hydrocarbon to oxygen-containing gas for complete combustion to carbon dioxide and water. The preferred composition is from 5 to 9 times the stoichiometric ratio of hydrocarbon to oxygen-containing gas.

The autothermal cracker may suitably be operated at a temperature greater than 5 500°C, for example greater than 650°C, typically greater than 750°C, and preferably greater than 800°C. The upper temperature limit may suitably be up to 1200°C, for example up to 1100°C, preferably up to 1000°C.

It is preferred, although not essential, to preheat the feedstock and the oxygen-containing gas to suitably 200 to 500°C, preferably 200-300°C.

10 The autothermal cracker may be operated at atmospheric or elevated pressure. Pressures of 1 to 30 bara may be suitable, preferably a pressure of 1.1 bara to 5 bara, for example, 1.8 bara is employed. However, a total pressure of greater than 5 bar absolute can also be suitably employed.

15 Preferably, the gaseous feedstock and the molecular oxygen-containing gas are fed to the autothermal cracker in admixture under a Gas Hourly Space Velocity (GHSV) of greater than 80,000 hr<sup>-1</sup> in order to minimise the formation of carbon monoxide and carbon dioxide. Preferably, the GHSV exceeds 200,000 hr<sup>-1</sup>, especially greater than 1,000,000 hr<sup>-1</sup>. For the purposes of the present invention GHSV is defined as:-

vol. of total feed at NTP/Time/( vol. of catalyst bed).

20 For further details of preferred methods of operation reference may be made to the aforesaid EP-B1-0332289; EP-B1-0529793; and EP-A-0709446.

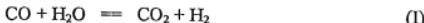
In addition to mono-olefins and synthesis gas, small amounts of acetylenes, aromatics and carbon dioxide are generally co-produced.

25 In step (b) of the process of the invention the product from step (a) of the process is separated into synthesis gas-containing stream and one or more mono-olefin(s) and the one or more mono-olefin(s) are recovered. Means for separating synthesis gas from mono-olefins are well-known in the art.

30 In step (c) of the process of the invention synthesis gas-containing stream separated in step (b) is contacted in alternative (i) with a catalyst for the conversion of synthesis gas to methanol under conditions whereby synthesis gas is converted to methanol and optionally thereafter, or simultaneously, the methanol so-formed is contacted with a catalyst for the dehydration of methanol to ethylene under conditions

whereby methanol is converted to ethylene and the ethylene, or optionally the methanol, or both, is recovered.

In alternative (ii) of step (c) of the process synthesis gas-containing stream separated in step (b) is contacted with a catalyst for the water gas shift reaction whereby 5 carbon monoxide in the synthesis gas is converted by reaction with water to hydrogen and carbon dioxide and thereafter hydrogen is recovered. The water gas shift reaction may be represented as:-



The water gas shift reaction is well-known in the art. It is generally operated in 10 the presence of a catalyst. Typically an iron oxide catalyst may be employed, although other catalysts known in the art may be employed. Temperatures typically in the range from 350 to 500°C may suitably be used. Conditions known in the art for driving the equilibrium towards the formation of hydrogen are preferably employed.

The water reactant may be some or all of the water produced as a by-product in 15 the oxidative dehydrogenation of the paraffinic hydrocarbon. Additionally further water may be added if desired.

In alternative (iii) of step (c) of the process of the invention synthesis gas-containing stream separated in step (b) is contacted with a catalyst for the conversion of synthesis gas to hydrocarbons under conditions whereby synthesis gas is converted to a 20 hydrocarbon product, and thereafter at least a part of the hydrocarbon product is recovered.

The conversion of synthesis gas into hydrocarbons has been known for many years, it being generally known as the Fischer-Tropsch (FT) process. The process produces hydrocarbons from C<sub>1</sub> upwards, but principally in the C<sub>5</sub>-C<sub>60</sub> range. In recent 25 years attention has been directed to the FT process as one of the more attractive direct and environmentally acceptable routes to high quality transportation fuels from alternative energy sources such as coal and natural gas via intermediate formation of synthesis gas. Thus, there may be recovered from the FT product a desirable hydrocarbon fraction boiling in the diesel range. There may also be recovered a less 30 valuable fraction of lower boiling point, which fraction is generally referred to as naphtha. Not all of this fraction is industrially utilisable. In a preferred embodiment the recovered naphtha fraction is recycled at least in part as feedstock to the autothermal

cracker in the process of the present invention. This leads to the advantage that the FT process and the process for the production of a mono-olefin by the oxidative dehydrogenation of a gaseous paraffinic hydrocarbon complement each other in the respect that the synthesis gas by-product of the oxidative dehydrogenation is useful as feed to the FT process and the lesser value naphtha product of the FT process is useful as a feedstock in the oxidative dehydrogenation. Moreover, a significant additional advantage is that the high pressure "fuel gas" stream comprising methane, carbon monoxide and hydrogen obtained from the conventional autothermal cracking separation via a demethaniser in step (II) may be used directly as feedstock to the FT reactor in step 5 (III) wherein the carbon monoxide/hydrogen component is consumed leaving methane and residual carbon monoxide as a more conventional fuel gas. Thus, the FT reactor functions as a reactor/sePARATOR adding value to the carbon monoxide/hydrogen and 10 eliminating a separation stage.

Accordingly, in a preferred embodiment the present invention provides an 15 integrated process for the production of a mono-olefin and a hydrocarbon fraction boiling in the diesel range which process comprises the steps of:

- (I) feeding a gaseous paraffinic hydrocarbon-containing feedstock and a molecular oxygen-containing gas to an autothermal cracker wherein they are reacted in the presence or absence of a catalyst capable of supporting combustion beyond the 20 normal fuel rich limit of flammability under conditions whereby the feedstock is oxidatively dehydrogenated to a product comprising one or more mono-olefin(s) and synthesis gas,
- (II) separating the product from step (I) into synthesis gas and one or more mono-olefin(s) and recovering the one or more mono-olefin(s),
- 25 (III) feeding synthesis gas separated in step (II), optionally together with additional synthesis gas, to an FT reactor containing an FT catalyst wherein the synthesis gas is reacted under FT conditions to produce an FT product comprising naphtha and hydrocarbons boiling in the diesel range,
- (IV) separating the FT product from step (III) into a naphtha fraction and a 30 diesel range hydrocarbon fraction and recovering the diesel range hydrocarbon fraction, and
- (V) preferably recycling the naphtha fraction recovered in step (IV) as feed to

the autothermal cracker of step (I).

Steps (I) and (II) of the preferred embodiment have been described hereinbefore.

As regards step (III) the catalyst may suitably comprise at least one metal selected from cobalt, nickel, iron, molybdenum, tungsten, thorium, ruthenium, rhenium, 5 and platinum. Of the aforesaid metals cobalt, nickel and iron are preferred. Generally, the metals may be used in combination with a support material. Suitable support materials include alumina, silica and carbon, and mixtures of two or more thereof. The use of cobalt, for example, as a catalytically active metal in combination with a support is well-known from, for example EP-A-127220; EP-A-142887; GB-A-2146350; GB-A- 10 2130113; EP-A-0209980; EP-A-0261870 and GB-A-2125062. Of these EP-A-127220, for example, discloses the use of a catalyst comprising (i) 3-60 pbw cobalt, (ii) 0.1-100 pbw zirconium, titanium, ruthenium or chromium, per 100 pbw silica, alumina or silica-alumina, (iii) the catalyst having been prepared by kneading and/or impregnation. EP-A-0209980 describes the use in the conversion of synthesis gas to hydrocarbons of a 15 catalyst having a composition represented by the formula:



wherein A is an alkali metal

a is greater than zero and up to 25% w/w,

b is in the range from zero to 5% w/w,

20 c is in the range from zero to 15% w/w,

x is a number such that the valence requirements of the other elements for oxygen is satisfied, and the remainder of the composition, subject to the requirement for x, is cerium.

EP-A-0261870 discloses a composition for use after reductive activation as a catalyst in 25 the conversion of synthesis gas to hydrocarbons, which composition comprises as essential components (i) cobalt either as the elemental metal, the oxide or a compound thermally decomposable to the elemental metal and/or oxide and (ii) zinc in the form of the oxide or a compound thermally decomposable to the oxide.

Any of the aforesaid catalysts may be used in the process of the present invention 30 and for further details of the catalysts their preparation and use reference may be made to the publications.

FT conditions are suitably a temperature in the range from 160 to 350°C,

preferably from 180 to 275°C, and a pressure in the range from 0 to 100 bar, preferably from 5 to 50 bar. The GHSV for continuous operation may suitably be in the range from 100 to 25000 h<sup>-1</sup>.

The process of step (III) may be carried out batchwise or continuously,  
5 preferably continuously, in a fixed bed, fluidised bed or slurry phase reactor.

The additional synthesis gas is suitably obtained by the partial oxidation of a carbonaceous substance, e.g. coal or by catalytic partial oxidation of methane, or liquified petroleum gases. Preferably, the synthesis gas is obtained by the catalytic steam reforming of methane, either as such or in the form of natural gas. Steam reforming and  
10 catalysts therefor are well-known in the art. Typically, a supported nickel catalyst is employed. The carbon monoxide to hydrogen ratio of the synthesis gas may suitably be in the range from 2:1 to 1:6, preferably from 2:1 to 1:2. Whilst the ratio of carbon monoxide to hydrogen in the synthesis gas produced by the aforesaid processes may differ from these ranges, it may be altered appropriately by the addition of either  
15 component, or may be adjusted by the shift reaction as mentioned hereinbefore.

In step (IV) of the preferred embodiment the FT product from step (III) is separated into a naphtha fraction and a diesel range hydrocarbon fraction. This separation may be accomplished by any of the means known in the art. Generally, the fractions may be separated by distillation. Preferably, the diesel range hydrocarbon  
20 produced in step (IV) is highly paraffinic, with good combustion characteristics. Preferably also, the diesel range hydrocarbon substantially no metal, nitrogen, sulfur or aromatic impurities. If such impurities are present however, their concentrations are kept to a minimum. For example, the sulphur content of the diesel fraction may be less than 0.01wt %, and more preferably less than 0.001 % weight. The diesel range hydrocarbon  
25 may have a density of 0.7 to 0.9 g/ml., preferably, 0.8 g/ml. Its pour point may be between -35 to -45°C, preferably about -38 to -40°C.

In step (V) the naphtha fraction recovered in step (IV) is preferably recycled as feed to the autothermal cracker of step (I). Alternatively some, or all, the naphtha fraction may be recovered, and used elsewhere.

30 A preferred embodiment of the invention will now be further described by reference to the accompanying drawings, in which:

Figure 1 is a simplified flow sheet showing a first embodiment of the present

invention in operation, and

Figure 2 is a simplified flow sheet showing a second embodiment of the present invention in operation.

Reference is first made to Figure 1 of the drawings, which depicts a first 5 embodiment of the present invention.

A paraffinic hydrocarbon feedstock, principally comprising ethane, is fed through line 1 to the autothermal cracker 4. Also fed to the autothermal cracker through line 2 is oxygen. The autothermal cracker 4 is maintained under conditions whereby oxidative dehydrogenation is effected to produce ethylene, higher olefins, methane, carbon dioxide, 10 and synthesis gas (carbon monoxide and hydrogen). The product is passed through line 5 to a product separation zone 6 wherein a mixture of synthesis gas and methane is separated cryogenically from ethylene and higher olefins. The ethylene and higher olefins are removed from the separation zone, for example, via lines 7 and 8.

The mixture of synthesis gas and methane recovered from the product separation 15 zone 6 is fed through line 9 to the FT reactor 13. Also fed to the reactor 13 through line 12 is synthesis gas produced by the steam reformer 11 to which is fed natural gas through line 10. In the FT reactor 13 synthesis gas is converted to hydrocarbons which are passed to the product separation zone 15 in which (i) methane is separated and recycled through line 18 as feed to the reformer 11, (ii) hydrocarbons boiling in the diesel 20 range are separated and recovered through line 16 and (iii) naphtha is separated and removed through line 17. At least a part of the naphtha is recycled through line 3 as feed to the autothermal cracker 4.

Reference is now made to Figure 2 of the drawings, which depicts an alternative embodiment to the embodiment depicted in Figure 1. Like parts are referred to with like 25 numerals.

With reference to Figure 2, oxygen is fed through line 2 to the autothermal cracker 4. Also fed to the autothermal cracker is recycled naphtha, which enters the cracker 4 via line 3. Unlike the embodiment of Figure 1, a paraffinic hydrocarbon feedstock is not introduced into the cracker via line 1. The autothermal cracker 4 is 30 maintained under conditions whereby oxidative dehydrogenation is effected to produce ethylene, higher olefins, methane, carbon dioxide, and synthesis gas (carbon monoxide and hydrogen). The product is passed through line 5 to a product separation zone 6

wherein a mixture of synthesis gas and methane is separated cryogenically from ethylene and higher olefins. The ethylene and higher olefins are removed from the separation zone, for example, via lines 7 and 8.

The mixture of synthesis gas and methane recovered from the product separation zone 6 is fed through line 9 to the FT reactor 13. Also fed to the reactor 13 is synthesis gas produced by the steam reformer 11 to which is fed natural gas through line 10. In the FT reactor 13, synthesis gas is converted to hydrocarbons which are passed to the product separation zone 15 in which (i) methane is separated and recycled through line 18 as feed to the reformer 11, (ii) hydrocarbons boiling in the diesel range are separated and recovered through line 16 and (iii) naphtha is recycled through line 3 as feed to the autothermal cracker 4. Unlike, the embodiment of Figure 1, all the naphtha produced in the FT reactor 13 is recycled. Water produced in the FT reactor 13 is removed through line 19. The hydrocarbon stream recovered through line 16 was analysed and found to be extremely paraffinic. The steam contained no metals, nitrogen, sulfur or aromatics, and had quality combustion characteristics. Table 1 below summarises the density, sulphur content and cetane number of the diesel produced:

Table 1

|                |                |
|----------------|----------------|
| density        | 0.79 g/ml      |
| pour point     | -39 C          |
| cetane number  | 75             |
| sulfur content | <0.001 %weight |

The flow rates through lines 2, 3, 5, 7 to 10, and 16 and 19 are tabulated below (Table 2).

Table 2

| Line Number | Flow rate (TE/hr) |
|-------------|-------------------|
| 2           | 85                |
| 3           | 200               |
| 5           | 304               |
| 7           | 83.4              |
| 8           | 20.8              |
| 9           | 105               |
| 10          | 908               |
| 16          | 466               |
| 19          | 467               |

5

10

15

20

Claims:

1. A process for the production of a mono-olefin from a feedstock comprising a paraffinic hydrocarbon which process comprises the steps of:
  - (a) feeding the feedstock and a molecular oxygen-containing gas to an autothermal cracker, where they are reacted by oxidative dehydrogenation to form a product comprising one or more mono-olefin(s) and synthesis gas,
  - (b) separating the product from step (a) into a synthesis gas-containing stream and one or more olefins and recovering the one or more olefin(s),
  - (c) contacting synthesis gas-containing stream separated in step (b) with either:-
    - (i) a catalyst for the conversion of synthesis gas to methanol under conditions whereby synthesis gas is converted to methanol; or
    - (ii) a catalyst for the water gas shift reaction under conditions whereby carbon monoxide in the synthesis gas is converted by reaction with water to hydrogen and carbon dioxide, and thereafter recovering hydrogen; or
    - (iii) a catalyst for the conversion of synthesis gas to hydrocarbons under conditions whereby synthesis gas is converted to a hydrocarbon product, and thereafter recovering at least a part of the hydrocarbon product.
2. A process as claimed in claim 1, which comprises the steps of c) contacting synthesis gas-containing stream separated in step (b) with i) a catalyst for the conversion of synthesis gas to methanol under conditions whereby synthesis gas is converted to methanol; d) thereafter, or simultaneously, contacting the methanol so-formed with a catalyst for the dehydration of methanol to ethylene under conditions whereby methanol is converted to ethylene, and e) recovering the ethylene, and/or optionally any

unconverted methanol.

3. A process as claimed in claim 1, wherein said catalyst for the water gas shift reaction of step c ii) comprises iron oxide.

4. A process as claimed in claim 1, which comprises the step of c) contacting  
5 synthesis gas-containing stream separated in step (b) with  
(iii) a catalyst for the conversion of synthesis gas to hydrocarbons under conditions whereby synthesis gas is converted to a hydrocarbon product, and thereafter recovering at least a part of the hydrocarbon product.

5. A process as claimed in claim 4, wherein part of the hydrocarbon product is  
10 recovered, and part of the hydrocarbon product is recycled to the autothermal cracker as the feedstock.

6. A process as claimed in claim 4 or 5, wherein the hydrocarbon product comprises a hydrocarbon fraction boiling in the diesel range, and/or a hydrocarbon boiling in the naphtha range.

15 7. A process as claimed in claim 6, wherein said hydrocarbon boiling in the naphtha range is recycled at least in part as feedstock to the autothermal cracker of part a).

8. An integrated process for the production of a mono-olefin and a hydrocarbon fraction boiling in the diesel range which process comprises the steps of:

20 (I) feeding a gaseous paraffinic hydrocarbon-containing feedstock and a molecular oxygen-containing gas to an autothermal cracker wherein they are reacted in the presence or absence of a catalyst capable of supporting combustion beyond the normal fuel rich limit of flammability under conditions whereby the feedstock is oxidatively dehydrogenated to a product comprising one or more mono-olefin(s) and synthesis gas,

25 (II) separating the product from step (I) into synthesis gas and one or more mono-olefin(s) and recovering the one or more mono-olefin(s),

(III) feeding synthesis gas separated in step (II), optionally together with additional synthesis gas, to an FT reactor containing an FT catalyst wherein the synthesis gas is reacted under FT conditions to produce an FT product comprising naphtha and hydrocarbons boiling in the diesel range,

30 (IV) separating the FT product from step (III) into a naphtha fraction and a diesel range hydrocarbon fraction and recovering the diesel range hydrocarbon fraction,

and

(V) preferably recycling the naphtha fraction recovered in step (IV) as feed to the autothermal cracker of step (I).

9 A process as claimed in claim 8, wherein said additional synthesis gas is obtained  
5 by the partial oxidation of a carbonaceous substance.

10. A process as claimed in any preceding claim, wherein the carbon monoxide to hydrogen ratio of the synthesis gas employed is 2:1 to 1:6.

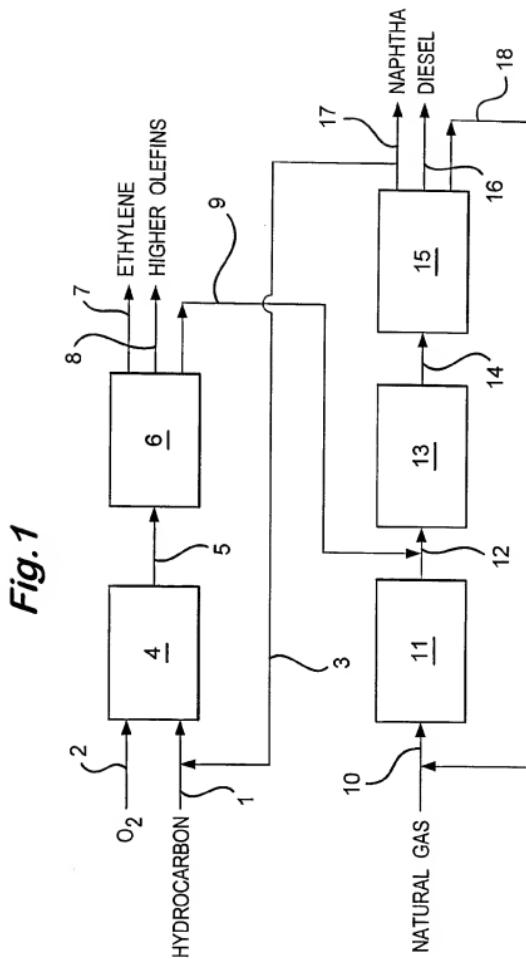
10

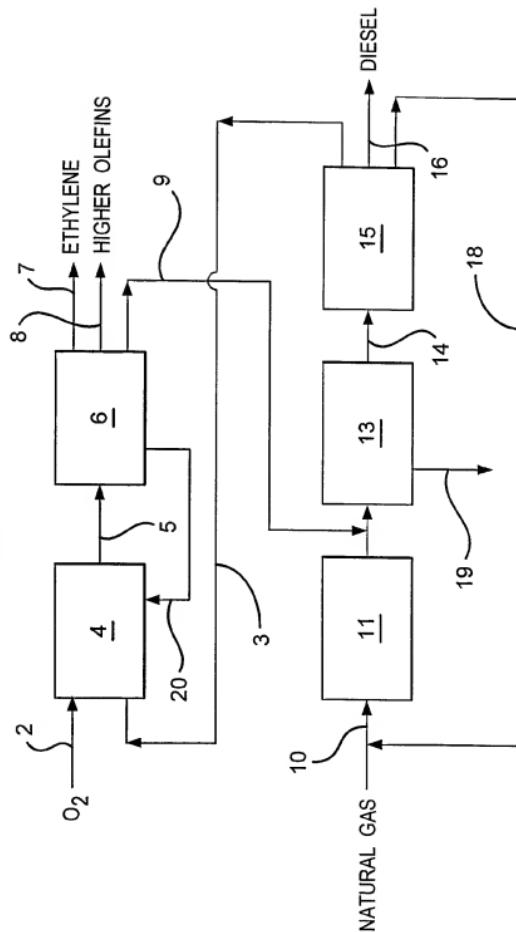
15

20

25

30



*Fig.2*

## INTERNATIONAL SEARCH REPORT

International Application No  
PCT/GB 99/02955

|                                     |          |           |            |
|-------------------------------------|----------|-----------|------------|
| A. CLASSIFICATION OF SUBJECT MATTER |          |           |            |
| IPC 7 C07C1/04                      | C10G2/00 | C07C11/04 | C07C29/151 |

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)  
IPC 7 C07C C10G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the International search (name of data base and, where practical, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages                                    | Relevant to claim No. |
|------------|-----------------------------------------------------------------------------------------------------------------------|-----------------------|
| Y          | DE 195 07 098 A (METALLGESELLSCHAFT AG)<br>5 September 1996 (1996-09-05)<br>claims 1,4,5<br>page 3, line 41 - line 46 | 1,3,4,10              |
| A          | GB 794 157 A (MONSANTO CHEMICAL CO)<br>cited in the application<br>claims 1,5,6                                       | 2                     |
| Y          | EP 0 199 475 A (BRITISH PETROLEUM CO PLC)<br>29 October 1986 (1986-10-29)<br>the whole document                       | 1,3,4,10              |
| A          | US 4 264 435 A (READ JR ARTHUR E ET AL)<br>28 April 1981 (1981-04-28)                                                 | 1,4                   |

Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

## \* Special categories of cited documents :

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the International filing date
- "L" document which may throw doubt on priority, claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the International filing date but later than the priority date claimed

"T" later document published after the International filing date or priority date and not in conflict with the application but which understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"Z" document member of the same patent family

Date of the actual completion of the International search

Date of mailing of the International search report

17 December 1999

11/01/2000

Name and mailing address of the ISA

Authorized officer

European Patent Office, P.B. 5018 Patentian 2  
NL - 2280 HV Rijswijk  
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,  
Fax: (+31-70) 340-3016

De Herdt, D

## INTERNATIONAL SEARCH REPORT

Information on patent family members

Int'l Application No

PCT/GB 99/02955

| Patent document cited in search report | Publication date | Patent family member(s) |            | Publication date |
|----------------------------------------|------------------|-------------------------|------------|------------------|
| DE 19507098 A                          | 05-09-1996       | CN                      | 1142526 A  | 12-02-1997       |
| GB 794157 A                            |                  | NONE                    |            |                  |
| EP 0199475 A                           | 29-10-1986       | AU                      | 594672 B   | 15-03-1990       |
|                                        |                  | AU                      | 5666486 A  | 23-10-1986       |
|                                        |                  | CA                      | 1266491 A  | 06-03-1990       |
|                                        |                  | WO                      | 8605775 A  | 09-10-1986       |
|                                        |                  | JP                      | 7045414 B  | 17-05-1995       |
|                                        |                  | JP                      | 62502402 T | 17-09-1987       |
|                                        |                  | NO                      | 174042 C   | 04-04-1995       |
|                                        |                  | NZ                      | 215679 A   | 06-01-1989       |
| US 4264435 A                           | 28-04-1981       | NONE                    |            |                  |